AMMRC CR 71-2/1

THE EFFECTS OF THE SURFACE LAYER ON PLASTIC DEFORMATION AND CRACK PROPAGATION

MARCH 1971

I. R. KRAMER
MARTIN MARIETTA CORPORATION
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DENVER, COLORADO

SEMI-ANNUAL

Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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ARPA ORDER 180-0-7400

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ABSTRACT

We have measured the rate of crack propagation as a function of frequency in Ripling type specimens of aluminum 2014-T6. It was observed that the rate of crack propagation was decreased from 1.7×10^{-5} in/cycle to 1.2×10^{-6} in/cycle when the frequency is increased from 1 to 20 cycles/second. It was also observed that the plot of crack length vs. number of cycles is linear indicating a constant rate of growth up to a crack length of one inch. The effect of prestressing followed by aging at 250°F for 2 to 4 hours was to decrease the rate of crack propagation from 1.02×10^{-6} to 9.8×10^{-7} in/cycle. This shows that prestressing followed by aging has a beneficial effect on the crack growth resistance of aluminum 2014-T6.

Center notched specimens of titanium (6 Aℓ-4V) were tested in tension under a cyclic stress of 7,000 to 28,000 psi. In the untreated specimen, the crack started to grow after 50,000 cycles. However, in the specimen which was prestressed 100,000 psi and the surface layer removed, the rate of crack propagation was zero. This shows that prestressing and surface removal has a beneficial effect on titanium (6 Aℓ-4V).

FOREWORD

This report was prepared by the Denver Division of Martin Marietta Corporation Under U. S. Army Contract No. DAAG 46-70-C-0102. The contract is sponsored by Advanced Research Project Agency under ARPA Order No. 188-0-7400 and is being adminstered by the Army Materials and Mechanics Research Center, Watertown, Massachusetts, with Dr. Eric B. Kula, AMXMR-RM, serving as Technical Supervisor.

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I. INTRODUCTION

Under this contract, we are investigating the effect of surface layer on the rate of crack propagation and based on this knowledge we propose to improve the crack propagation resistance of metals used in pressure vessels. The qualification of pressure vessel hardware is usually achieved by the proof test method. The maximum size of the flaw that is present can be predicted from fracture mechanics. However, cracks can grow below the critical stress intensity K_c and can cause leak failure. Therefore, the subcritical crack growth characteristics of metals are important in pressure vessel material selection. An evaluation of the crack growth rate under sustained or cyclic loading under the service stress gives a measure of reliability of the hardware.

The evidence that surface layer is important in crack propagation rate may be obtained by measurements of fatigue life and surface layer stress in a vacuum environment. It is well established that the fatigue life of metals is much greater in vacuum than under atmospheric conditions. The rate of crack propagation is much slower under vacuum and thus the number of cycles required to propagate a crack is increased. We have measured the surface layer stress of titanium (6 Aℓ-4V) under corrosive environment and found it is much greater than that under atmospheric conditions. Further, the rate of relaxation was also much slower.

II. EXPERIMENTAL RESULTS

We have procured 1/8" thick sheet of aluminum 2014-T6 alloy. A calculation shows that in order to get away from the end effects and get crack propagation below the yield stress, the minimum width of the sheet required for center notched specimens is 6". The capacity of our MTS system is only 6,000 pounds. Therefore, we have decided to use the Ripling M-4 specimen for aluminum 2014-T6. Another advantage of the Ripling specimen is that the taper keeps the stress intensity K constant and independent of the crack length. Ripling type specimens as shown in Figure 1 were machined out of the sheet stock. A portion of the sheet stock was cut into blanks 6" x 6" and prestressed to 33,000 psi and later Ripling specimens were machined out. These specimens will be referred to as prestressed specimens. All the specimens were stress relieved and electrolytically polished to remove 0.005 from the surface. A starter flaw was introduced with a file and jeweler's saw. The specimens were loaded in a MTS machine. A special loading jig was designed and manufactured to prevent buckling of the specimen. Lubricated teflon was used to minimize friction between the backing plate and specimen. The MTS machine was programmed to cycle the load between two limits. The effect of changing the frequency of loading in a typical test is shown in Figure 2. It is observed that the rate of crack propagation da/dN, where da is the change in crack length with a change in the number of cycles dN, decreases from 1.7×10^{-5} in/cycles to 1.2×10^{-5} in/cycles when the frequency of the applied load is increased from 1 to 20 cycles per second. It is also observed in Figure 2 that the plot of crack length vs. number of cycles is linear indicating a constant da/dN which means that the K value is independent of the crack length. Therefore, all measurements were confined to the first one inch of crack length. The effect of prestressing 33,000 psi and surface removal (SSR) on the rate of crack propagation is shown in Figure 3. It is observed that SSR treatment increases da/dN from 1.03×10^{-6} to 1.14×10^{-6} inch/cycle. The effect of prestressing followed by aging at 250°F for two and four hours in also shown in Figure 3. It is observed that prestressing followed by aging definitely reduces the rate of crack propagation from 1.03×10^{-6} to 9.8×10^{-7} inch/cycle. We have previously shown that the fatigue life of aluminum 7075-T6 was increased by a similar treatment.

We have measured the rate of crack propagation in titanium (6 Aℓ-4V) Ripling specimens. The crack did not remain on its path and had strong tendency to veer off to one side or the other. Grooving procedures were employed without much success. Therefore, we have decided to test the titanium (6 Aℓ-4V) alloy in tension. Center notched specimens as shown in Figure 4 were machined out of 0.067" sheet stock and annealed at 1300°F for one hour. Another batch of specimens was prestressed to 100,000 psi. The surface of all the specimens was electrochemically polished. The specimens were drilled with an 1/8" drill and starter cracks were put in with a jeweler's saw. The specimens were loaded in a MTS machine. The crack length as a function of number of cycles for specimens cycled under a load (28,000 psi - 7,000 psi) is shown in Figure 5. It is observed that in untreated specimens, the starter crack starts propagating in 50,000 cycles and the rate of crack propagation increases with crack length. However, for the SSR treated specimens the starter crack did not propagate at all even after 1,000,000 cycles. This shows that SSR treatment is beneficial. At present we are increasing the stress to compare the rate of crack propagation in the untreated and SSR treated specimens of titanium (6 Aℓ-4V). In the case of aluminum 2014-T6 we are increasing the amount of prestress to see if there is any beneficial effect on the crack propagation resistance. In our previous work on 7075-T6 aluminum, it was found that the fatigue life increased with increasing prestress, up to the proportional limit.

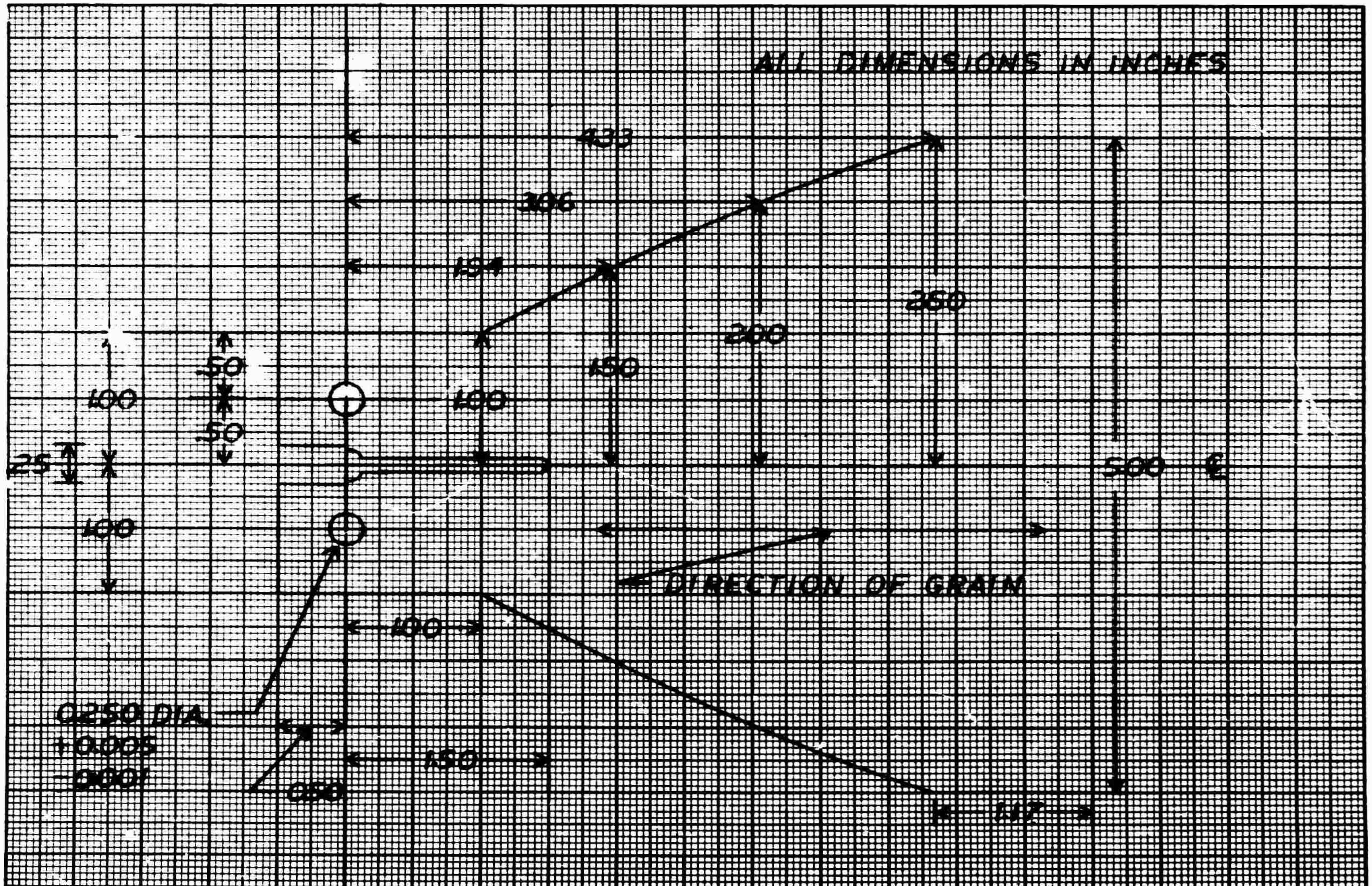


FIGURE 1. RIPLING TYPE M-4 TEST SPECIMEN

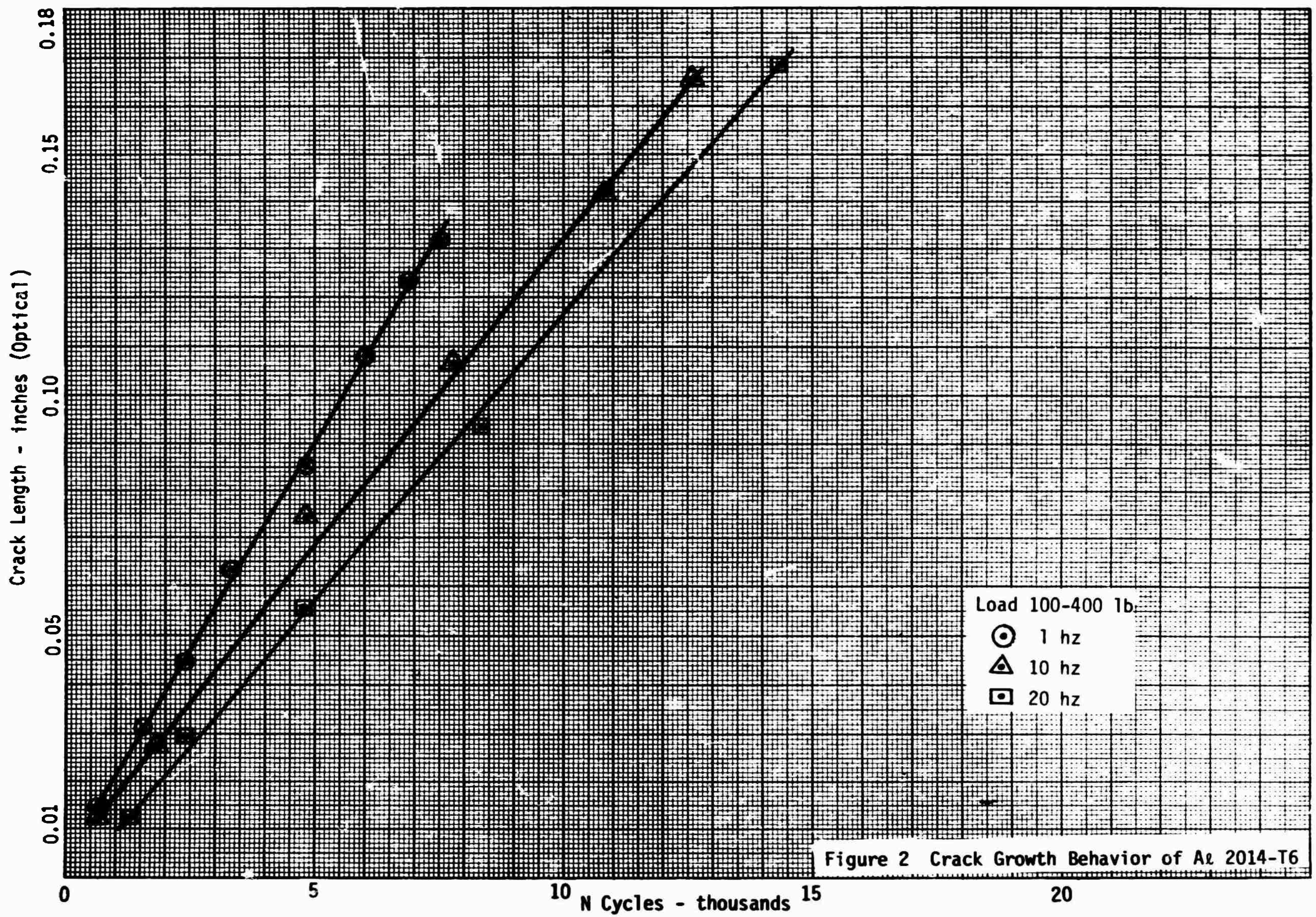


Figure 2 Crack Growth Behavior of Aℓ 2014-T6

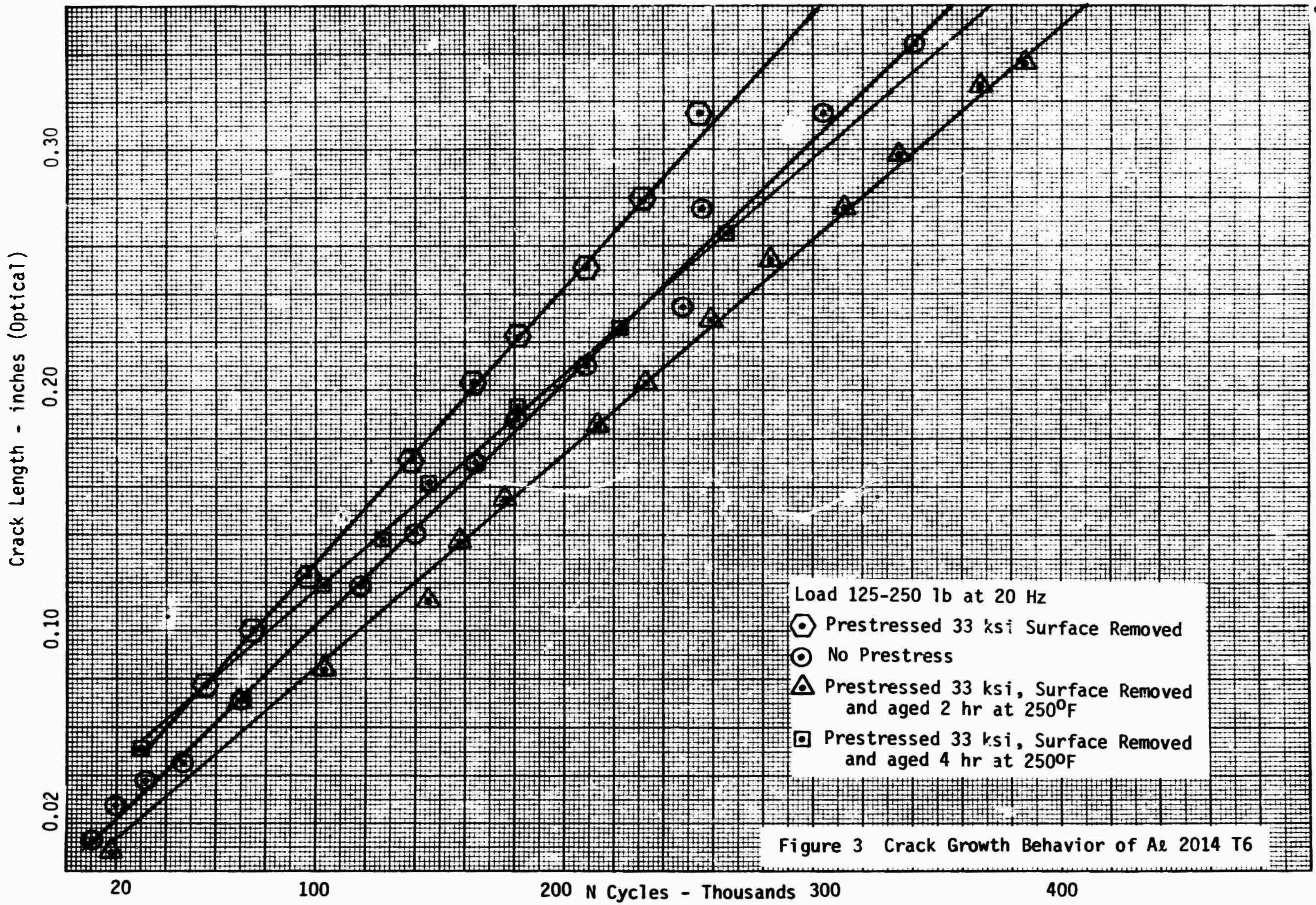
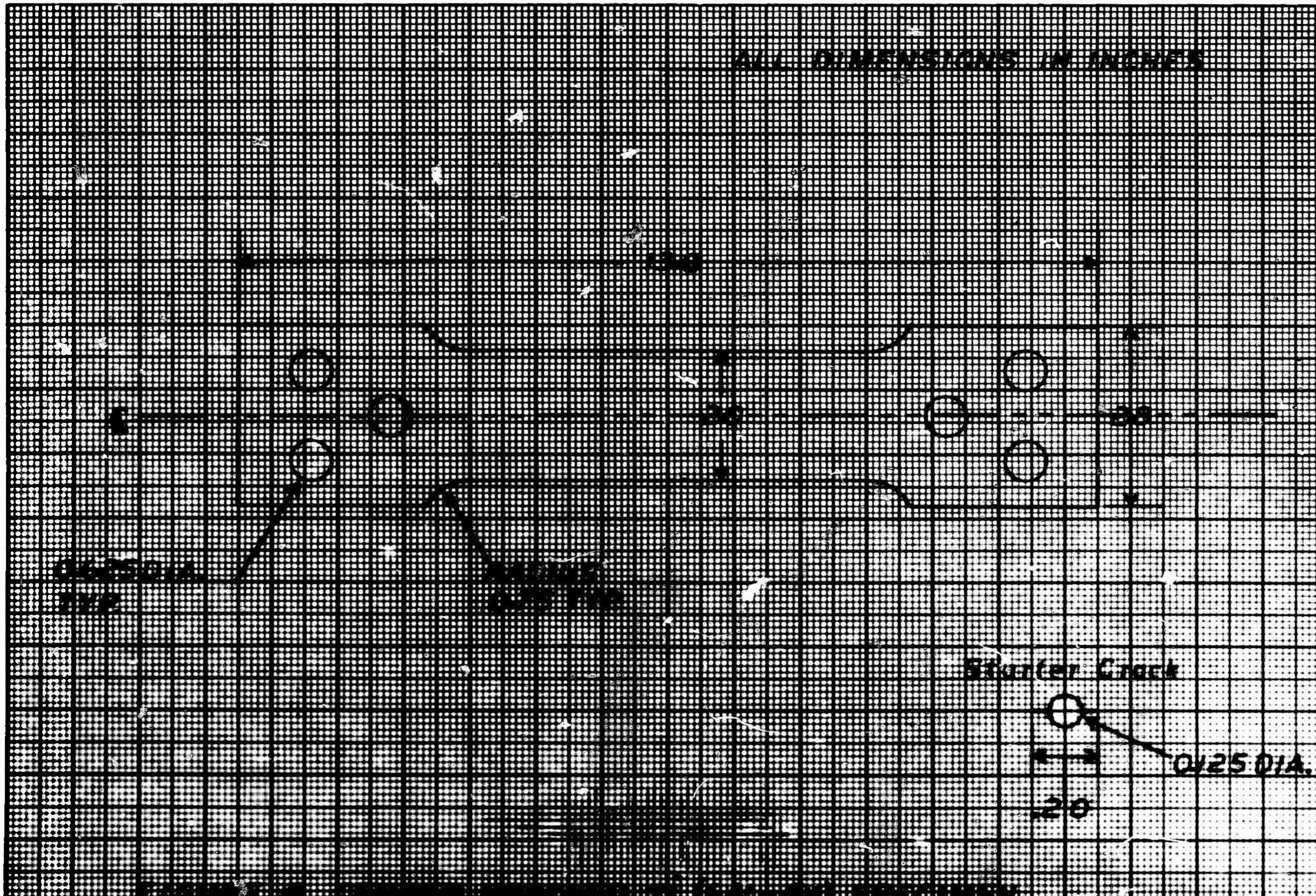


Figure 3 Crack Growth Behavior of Aℓ 2014 T6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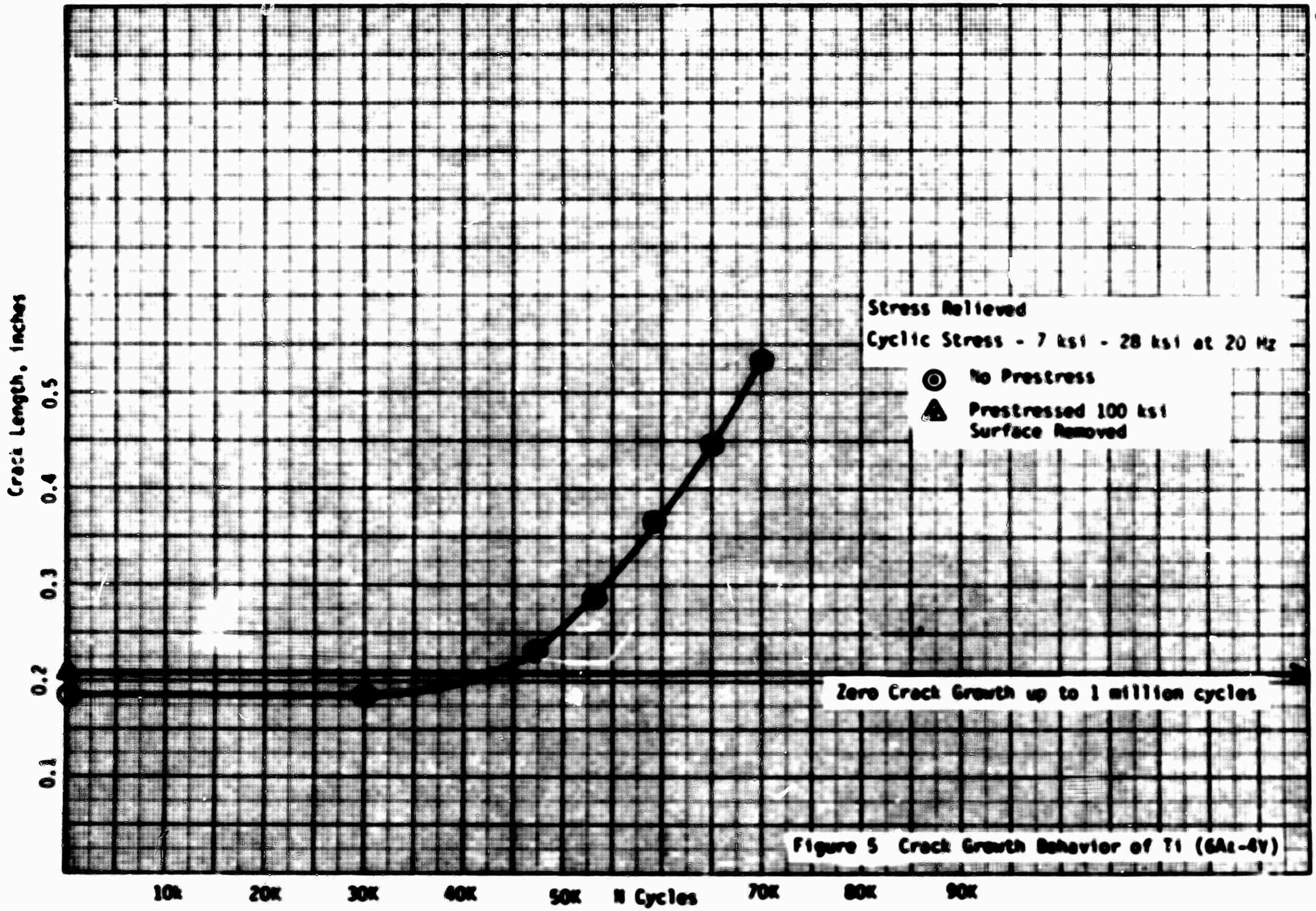

Figure 5 Crack Growth Behavior of Ti (6Al-4V)

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The Effects of the Surface Layer on Plastic Deformation and Crack Propagation

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Stress Intensity						
Crack Growth						
Surface Layer						
Ripling Specimen						

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